Historical Estimates of Agricultural and Wetland Water Use in the San Joaquin-Sacramento River Delta

By

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This report presents the results of a study comparing the water requirements (ET_c) of irrigated crops and wetland vegetation (tules and cattails) in the San Joaquin-Sacramento River Delta for different water years 1998 (wet), 2000 (average), and 2001 (dry). These are the most recent dry, normal, and wet years, which were used in the California Water Plan Update 2005. The main purpose of this project was to specifically customize the daily water balance program "Delta Evapotranspiration of Applied Water" or "DETAW" to analyze historical climate data to compute the water requirements of wetland vegetation that change from year-to-year. To do the analysis, DETAW was modified to sum the number of hectares of irrigated land for each of the 168 sub-areas within the Delta from 1921 to 2003. DETAW uses the product of reference evapotranspiration (ET_o) and a crop coefficient (K_c) factor to estimate well-watered evapotranspiration ($ET_c = ET_o \times K_c$). Using the surface areas, volumes of water corresponding to ET_c were computed for wetland vegetation on each the sub-areas over the period of record. The K_c values, crop type, and the percentages of the season to identifiable growth dates b, c, and d were changed to K_c factors and dates for tules and cattails to estimate daily and monthly ET data for wetland vegetation. The growth dates were b (10% ground cover), c (75% ground cover), and d (the onset of senescence). The model K_c values for tules and cattails, grown in standing water, were reported by Drexler et al. (2006). Since it is unlikely that the entire Delta area would have standing water for a full season, and the K_c factors are likely to be lower without the water, the standing-water K_c values provide an upper-limit boundary for estimating ET_c, and lower values are likely in most years. In drought years, the soil may dry out sufficiently to cause evapotranspiration (ET) reducing water stress, and a stress (K_s) coefficient might be needed to reduce the actual ET (ET_a) to a level lower than ET_c.

A comparison of *ET* of agricultural crops with the maximum wetland *ET* showed that the land use conversions from all existing irrigated crops to wetland vegetation could potentially increase ET_c in the Delta by about 20% from 3.40 acre-feet/acre to 4.18 acre-feet/acre during a normal water year (2000). Similar results were observed for the Delta Lowlands and Uplands. When irrigated winter cereal and grapevine cropped areas are not converted to cattails and tules, the wetland vegetation could increase ET_c by about 16% from 2.98 acre-feet/acre to 3.57 acre-feet/acre in a normal water year.

Water Balance Calculations:

DETAW was written in Borland Professional C^{++} to estimate daily soil water balances for surfaces within the Sacramento River - San Joaquin River Delta region that account for ET losses and water contributions from rainfall, seepage of ground water, and irrigation. The DETAW computer application was designed to process large numbers of crops and locations to determine crop evapotranspiration (ET_c) and evapotranspiration of applied water (ET_{aw}) for 168 sub areas in the Delta. Note that ET_{aw} is the amount of applied, irrigation water that contributes to evapotranspiration. Therefore, ET_{aw} is the amount of diverted water needed to produce a crop or maintain an urban landscape. It uses 82 years of daily measured weather data from the Lodi NCDC climate station to estimate reference evapotranspiration (ET_o) and correction factors, based on analysis of CIMIS data, to spatially estimate the daily Penman-Monteith equation estimate of ET_o for each SA within the Delta. Daily weather data include maximum (T_m) and minimum (T_n) air temperature and daily rainfall (*Pcp*). Using correction coefficients developed with GIS, precipitation is estimated every day of the 82 years using rainfall records from six climate stations located around the Delta. DETAW uses batch processing to read (1) the temperature and precipitation data, (2) the surface/crop coefficient values, (3) growth dates to estimate annual curves, (4) soil information, (5) crop and irrigation information, and (6) the surface area of each land-use category on each of the 168 SA. Then the program computes daily ET_o, K_c factors, ET_c, daily water balance, effective rainfall, ET_{aw}, etc. for every surface within each of the 168 SA for the 82 year period. Then the surface areas were used to compute volumes of water corresponding to ET_c for each surface on each of the 168 SA and ET_{aw} for irrigated surfaces. The application also accounts for seepage contributions from water bodies to ET_c of the irrigated land surfaces, and it estimates soil evaporation using a 2-stage soil evaporation model based on ET_o and surface wetting frequency. Finally, DETAW provides the ability to investigate critical (dry) and non-critical years, which have different land-use areas, and it can be used to project future ET_{aw} estimates as well as the historical records. The customized version of DETAW program estimates daily water balance for the six land-use groups for the each sub-areas in the Delta using the historical land-use data over the period of record. The land-use groups include urban, agriculture, riparian, wetland, water surface, and native vegetation. The open water, natural vegetation, non-irrigated cereals, and urban areas in the model were not changed when computing the ET_c after replacing crops with wetlands. Two possible changes were investigated. In one case, all irrigated crop surfaces were converted to wetland vegetation (case 1). In the other case, all irrigated crop surfaces except irrigated winter cereals and grapevines were converted to wetland vegetation. The second case was included because grapevines are the only summer crop with a low midseason K_c factor and irrigated winter cereals are generally harvested before midsummer. Including grapevines and irrigated winter cereals tends to bias the annual, Delta-wide crop ET_c downward.

ET of Applied Water (ET_{aw}):

By definition, ET_{aw} is the amount of applied irrigation water that contributes to ET_c; therefore, ET_{aw} is the sum of the net irrigation applications during a cropping season. Thus, ET_{aw} for *n* irrigation events is calculated as:

$$ET_{aw} = NA_1 + NA_2 + \cdots + NA_n \text{ .}$$

Alternatively, ET_{aw} can be calculated as the seasonal total evapotranspiration (CET_c) minus the cumulative effective seepage contribution (CE_{spg}) minus the cumulative effective rainfall contribution (CE_r) minus the difference in soil water content (ΔWC) from the beginning to the end of the season (Figure 1). The cumulative change in daily oil water (D_{sw}) curve is, by definition calculated as

$CD_{sw} = CET_c - CE_{spg} - CE_r$. Therefore, the ET_{aw} can also be expressed as

$ET_{aw} = CD_{sw} - \Delta WC$. Figure 1 illustrates how one can determine ET_{aw} from CET_c, CE_{spg}, CE_r, CD_{sw}, and ΔSW. The ΔSW is unknown until the end of the season, so ET_{aw} cannot be computed until the end of a cropping season using this method. The ET_{aw} can be computed as the sum of the net applications after the last *NA* is applied. This is the method used to determine the ET_{aw} in DETAW.

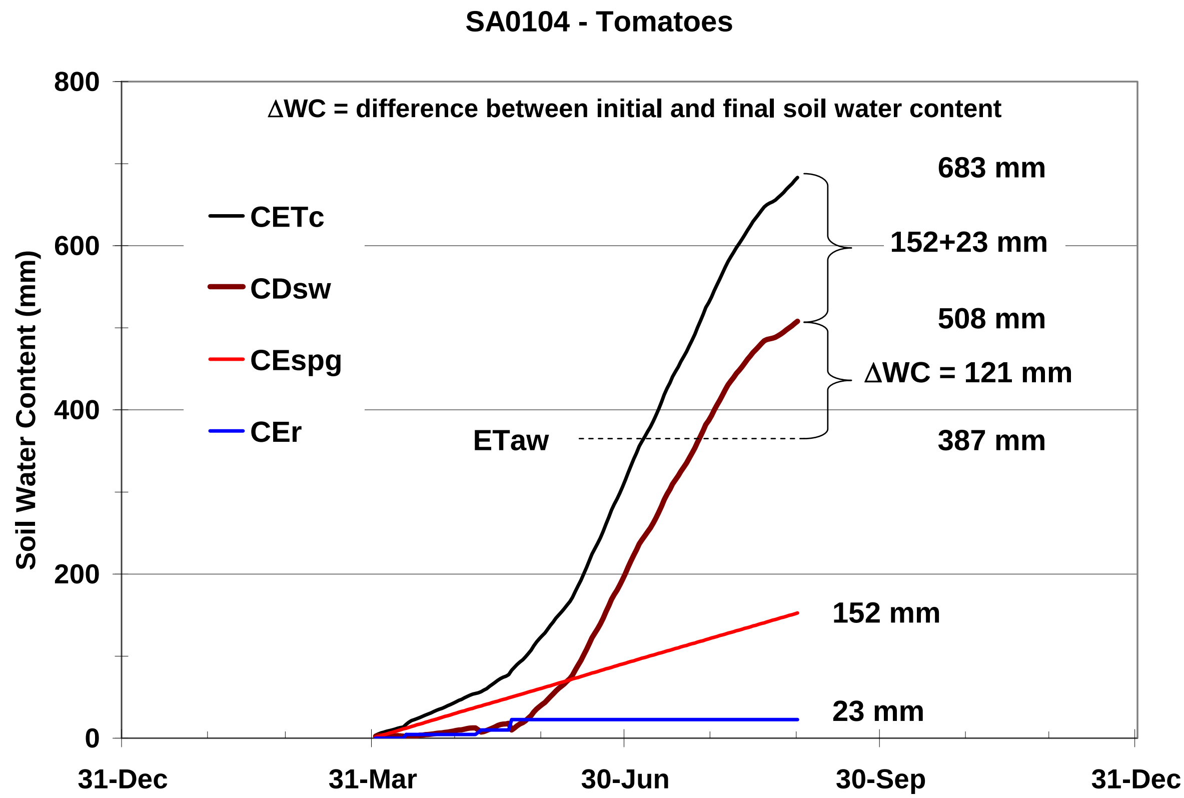


Figure 1. A plot of CET_c, CE_{spg}, CE_r, and CD_{sw} versus time for a tomato crop using data from the 1922 growing season from Delta sub-area 104.

The general form of consumptive use equation is

$ET_c = K_c \times ET_o$ (1),

where the K_c factor is an empirically determined crop coefficient relating ET_c to reference evapotranspiration (ET_o), which is a measure of evaporative demand that is only affected by the weather. Theoretically, ET_o is the *ET* of a 12-cm tall vegetative surface of large extent with a fixed canopy resistance and an aerodynamic resistance that is inversely proportional to the wind speed. ET_o, however, is approximately equal to the ET of a 12 cm tall, cool-season pasture grass, with no shortage of water to limit transpiration.

The daily change in soil water content, without considering irrigation, is calculated as

$D_{sw} = ET_c – E_{spg} - E_r$ (2),

where E_{spg} is the effective water contribution from seepage, E_r is the effective rainfall, and D_{SW} represents the increase in soil water depletion (or decrease in water content) each day. Therefore, when there is no irrigation, the soil water depletion (i.e., the difference between field capacity and the soil water content) on any given day is calculated as

$S_{WD} = S_{WDP} + D_{SW}$ (3),

where S_{WDP} is the soil water depletion on the previous day. Equation 3 is used for all non-irrigated surfaces except open water. For irrigated land-use surfaces, the net irrigation application (NA) is subtracted from the soil water depletion to estimate the S_{WD} following an irrigation event using the equation

$S_{WD} = S_{WDP} + D_{SW} - NA$ (4).

For riparian vegetation, wetland vegetation, water surfaces, native vegetation, and non-irrigated grain crops there is no irrigation, so NA always equals zero and there is no ET_{aw}. For urban surfaces, the irrigated portion of the land area is estimated to determine the ET_{aw}.

To determine how much water would be consumed by wetland vegetation relative to Agricultural ET, crop ET was estimated using historical records and DETAW. Then the agricultural land was converted to wetland surfaces to make the comparison. When calculating the wetland ET_c, it was assumed that the wetlands consisted of cattails and tules in standing water. The K_c factors for cattails and tules grown in standing water were taken from Drexler et al. (2006).

DETAW was executed using 82 years of daily temperature data from a climate station in Lodi to estimate daily ET_o rates across the Delta. Then the crop and soil information were used to make historical daily water balance calculations for the 16 land-use categories by sub-area (SA) for the 82 year study period. The 16 categories include urban, irrigated pasture, Alfalfa, All field, Sugar beets, Irrigated Grain, Rice, Truck Crops, Tomato, Orchard, Vineyard, Non-Irrigated Grain, Native vegetation, Riparian, and Tulles and Cattails. To determine how changing irrigated crop land to wetland vegetation would affect the evapotranspiration rate in the Delta, the calculated monthly and annual evapotranspiration values of agricultural crops and wetland vegetation were compared during 1998, 2000, and 2001 time periods. The results are presented in the following pages.

DETAW Validation:

The CUP or "Consumptive Use Program" (Orang et. al., 2004) was used as a tool to validate the DETAW output of crop and wetland ET_c values for one sub-area prior to analyzing the entire Delta with DETAW. Using the data from sub-area 1 (i.e., Union Island East), a comparison of the ET_c values from CUP and DETAW is shown in Figures 2 and 3. Clearly, DETAW and CUP gave nearly identical values for ET_c.

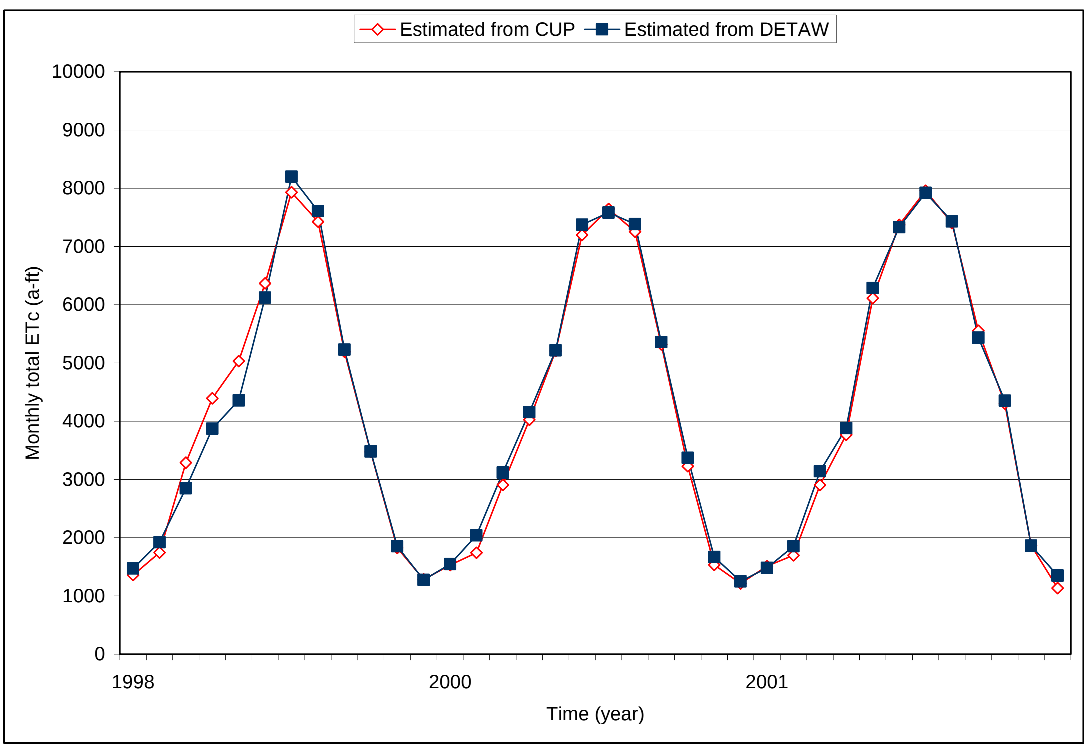


Figure 2- Comparison of monthly total estimates of evapotranspiration for tules and cattails from CUP and DETAW in sub-area 1 in the Delta during 1998 (wet), 2000 (average), and 2001 (dry) periods.

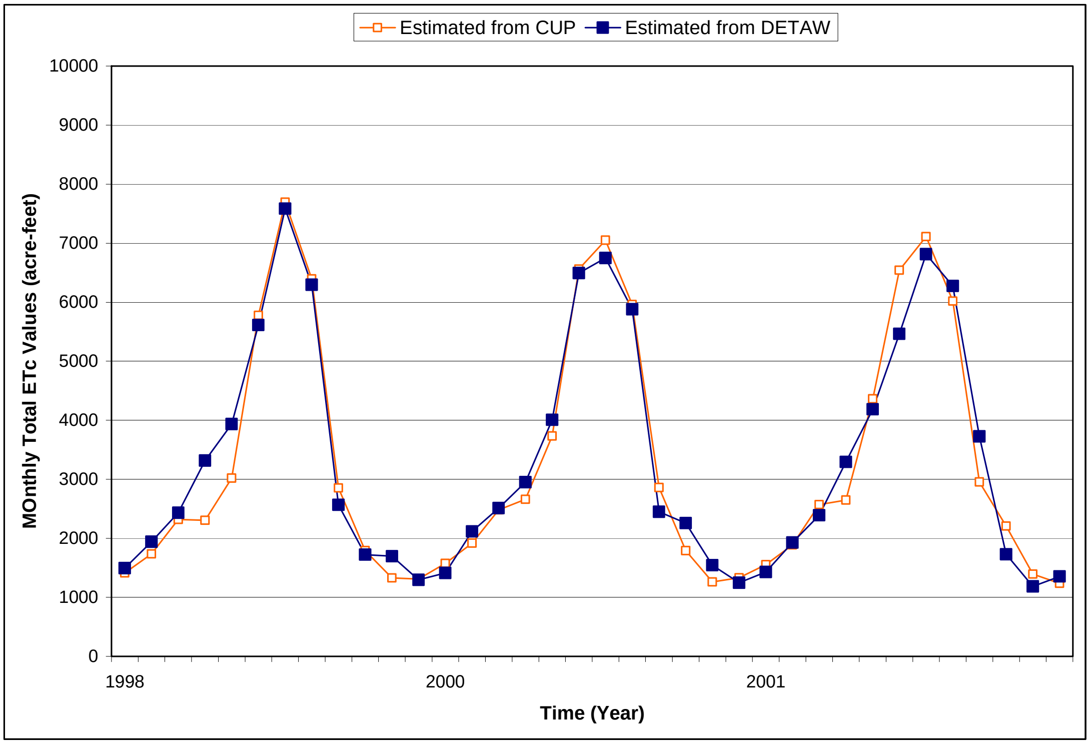
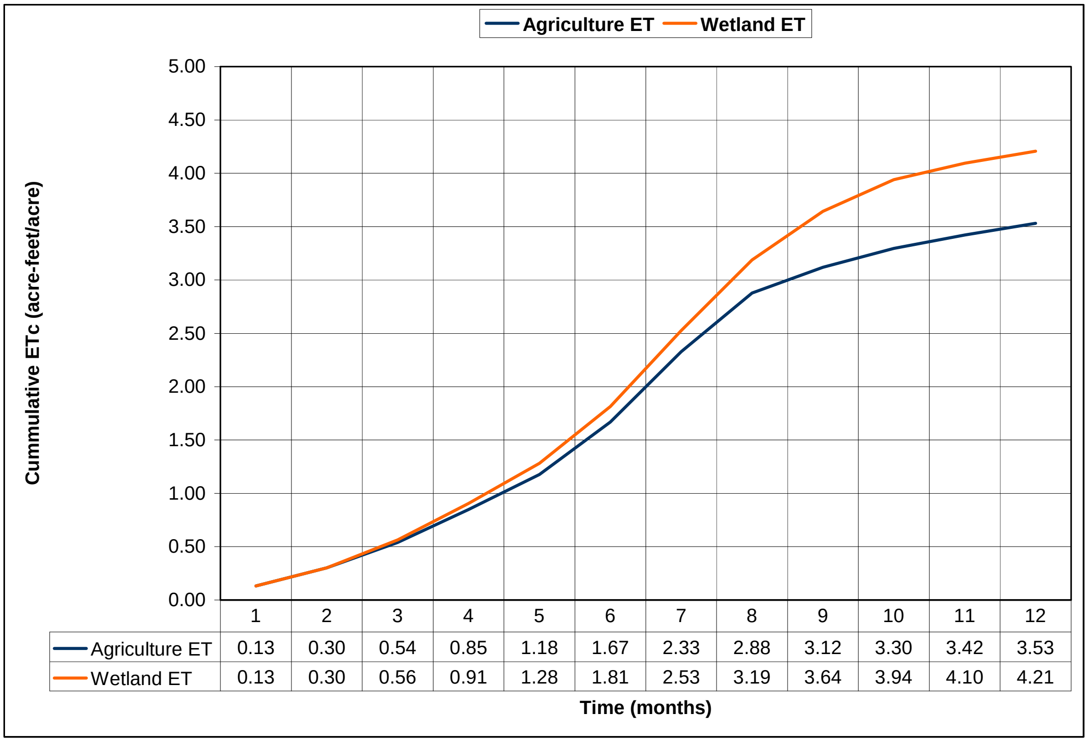


Figure 3- Comparison of monthly total estimates of evapotranspiration for agriculture from CUP and DETAW in sub-area 1 in the Delta during 1998 (wet), 2000 (average), and 2001 (dry) periods.

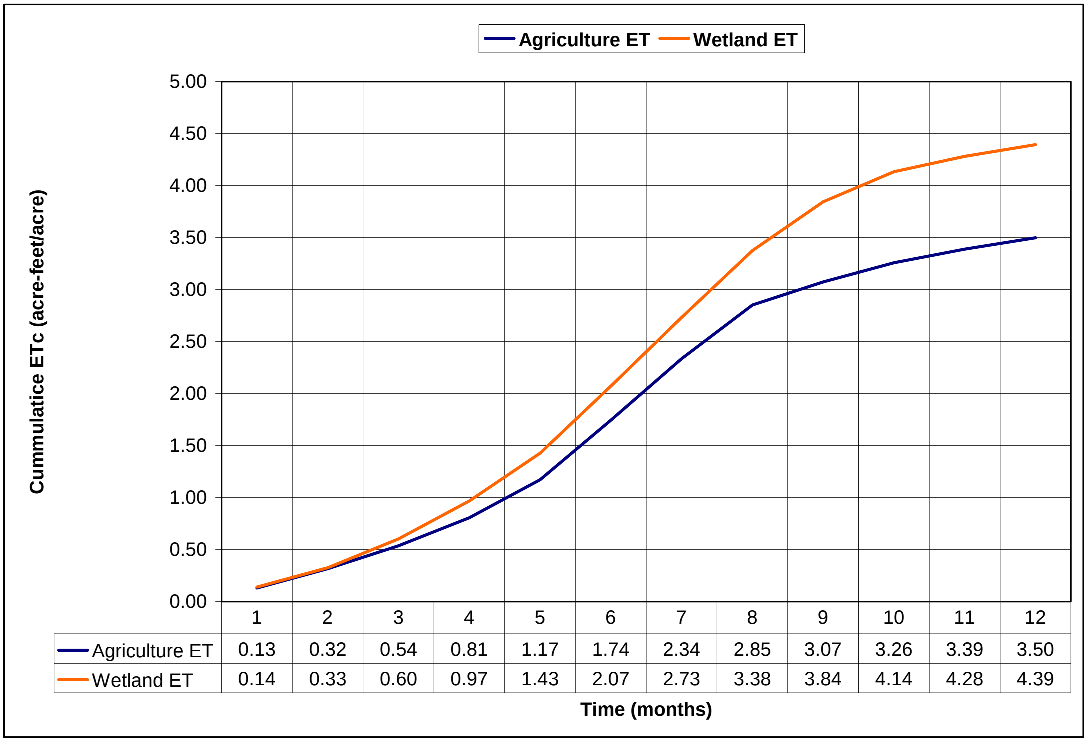
Results and Discussion:

The monthly cumulative values of agricultural and wetland ET_c estimated by DETAW were plotted against time (months) for 1998, 2000, and 2001 in Figures 4-6 for the Lowlands, in Figures 7-9 for the Uplands, and in Figures 10-12 for the entire Delta. For the entire Delta, the ET_c for the wetland cattails and tules was about 16% (1998), 20% (2000), and 22% (2001) higher than the agriculture-crop land-use group, which included irrigated pasture, alfalfa, all field crops, sugar beets, irrigated grain, rice, truck crops, tomato, orchard, vineyard, and non-irrigated grain (Figures 10-12). The results were similar for the Lowlands (Figures 4-6) and for the Uplands (Figures 7-9). When irrigated winter cereal and grapevine cropped areas are not converted to wetland vegetation in the Delta, the cattails and tules could increase evapotranspiration (ET_c) by about 13% in 1988 and 16% in 2000 and 2001, respectively.



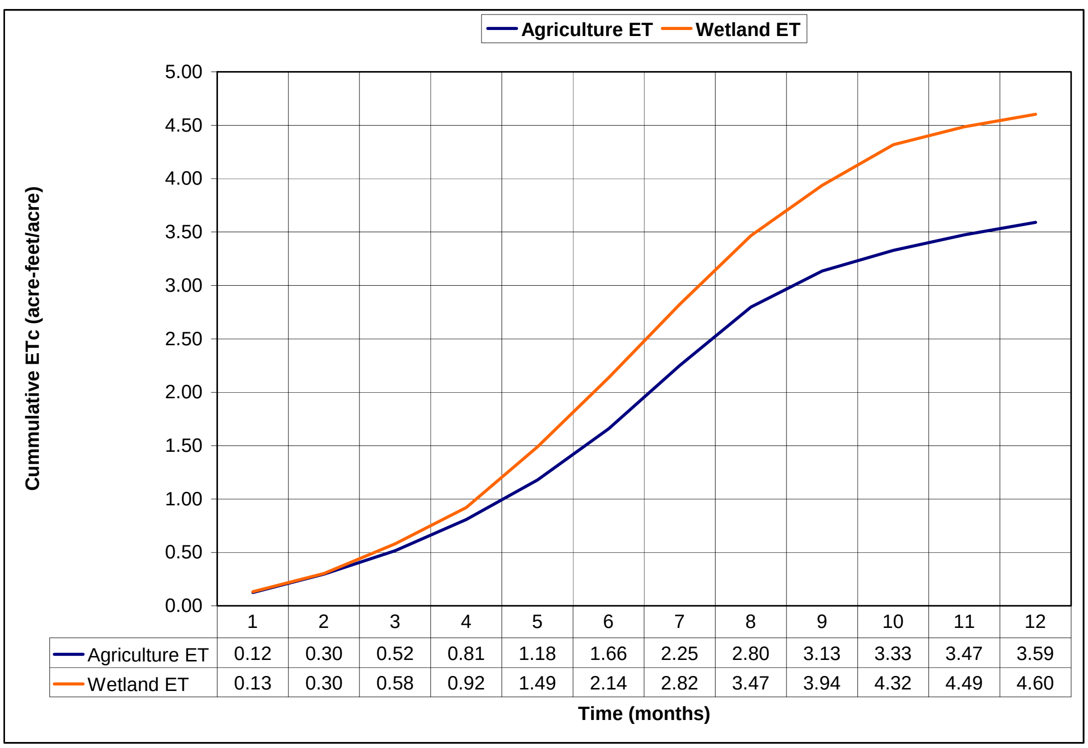
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.13	0.30	0.54	0.85	1.18	1.67	2.33	2.88	3.12	3.30	3.42	3.53
Wetland ET	0.13	0.30	0.56	0.91	1.28	1.81	2.53	3.19	3.64	3.94	4.10	4.21

Figure 4- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Lowlands during 1998.



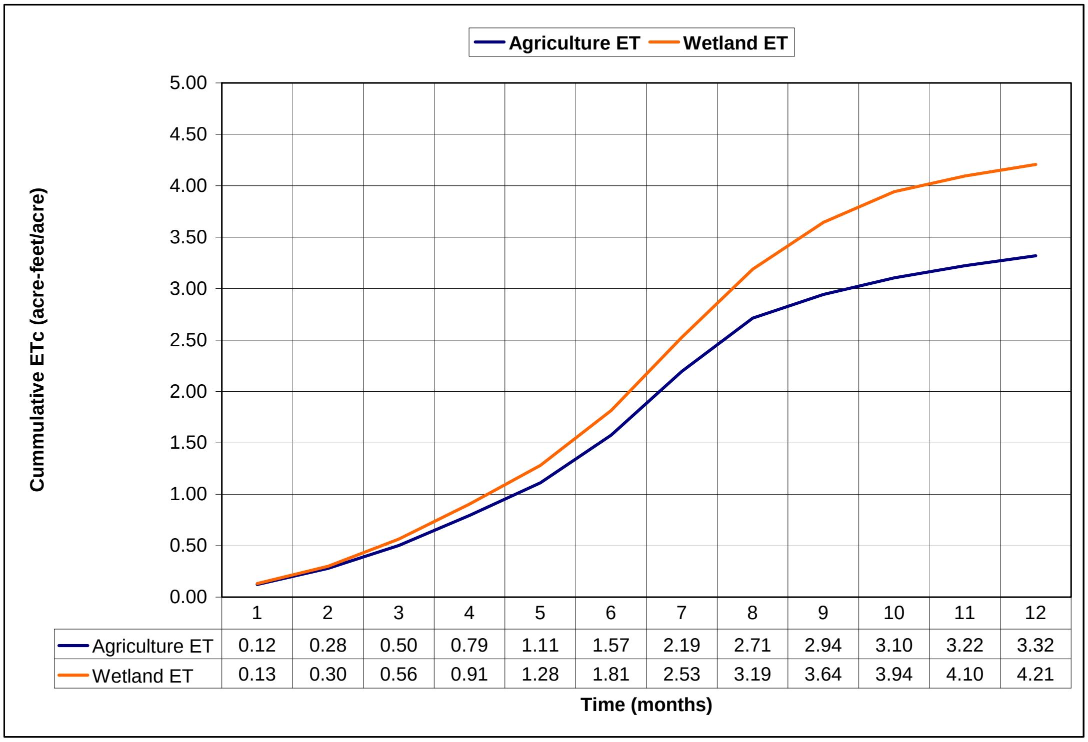
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.13	0.32	0.54	0.81	1.17	1.74	2.34	2.85	3.07	3.26	3.39	3.50
Wetland ET	0.14	0.33	0.60	0.97	1.43	2.07	2.73	3.38	3.84	4.14	4.28	4.39

Figure 5- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Lowlands during 2000.



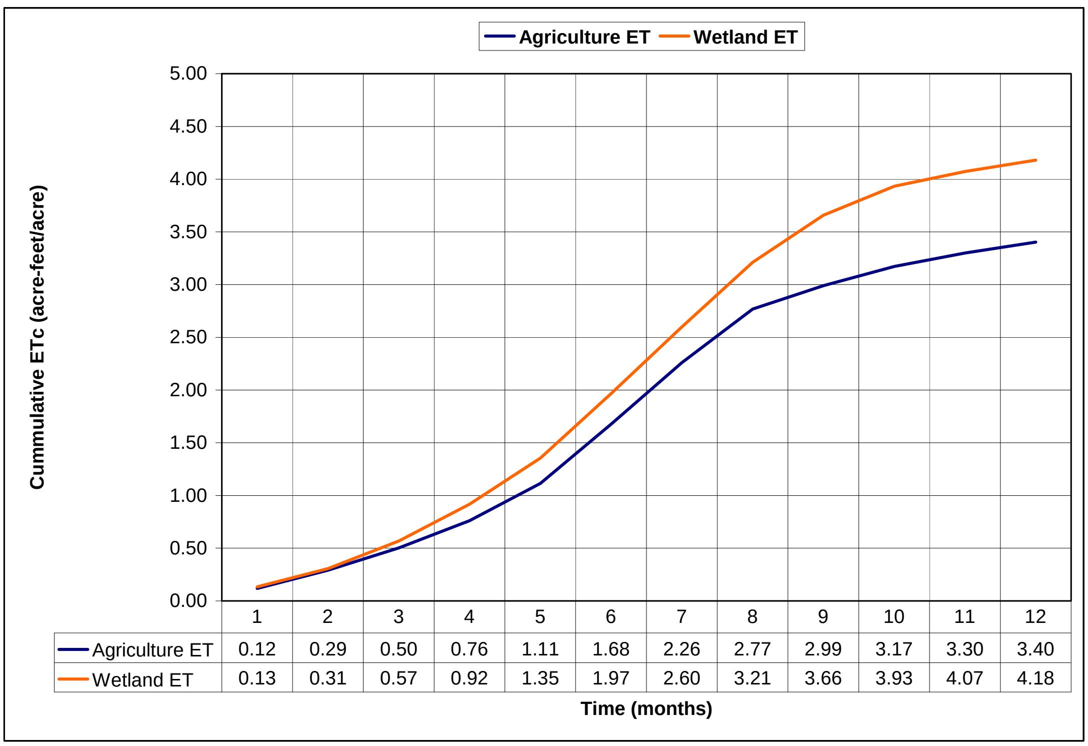
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.12	0.30	0.52	0.81	1.18	1.66	2.25	2.80	3.13	3.33	3.47	3.59
Wetland ET	0.13	0.30	0.58	0.92	1.49	2.14	2.82	3.47	3.94	4.32	4.49	4.60

Figure 6- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Lowlands during 2001.



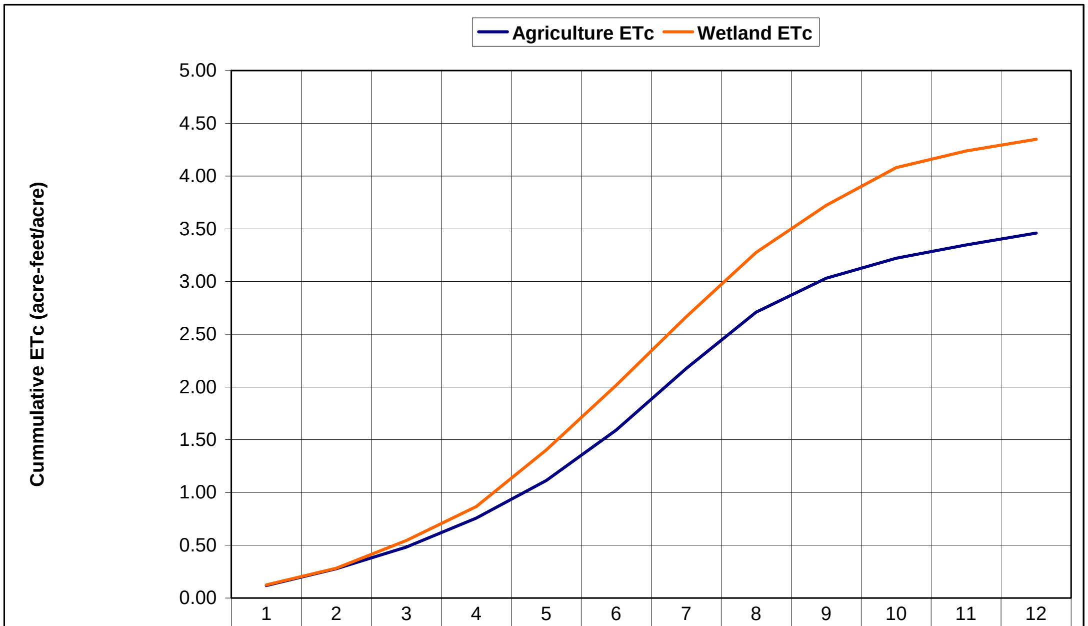
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.12	0.28	0.50	0.79	1.11	1.57	2.19	2.71	2.94	3.10	3.22	3.32
Wetland ET	0.13	0.30	0.56	0.91	1.28	1.81	2.53	3.19	3.64	3.94	4.10	4.21

Figure 7- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Uplands during 1998.



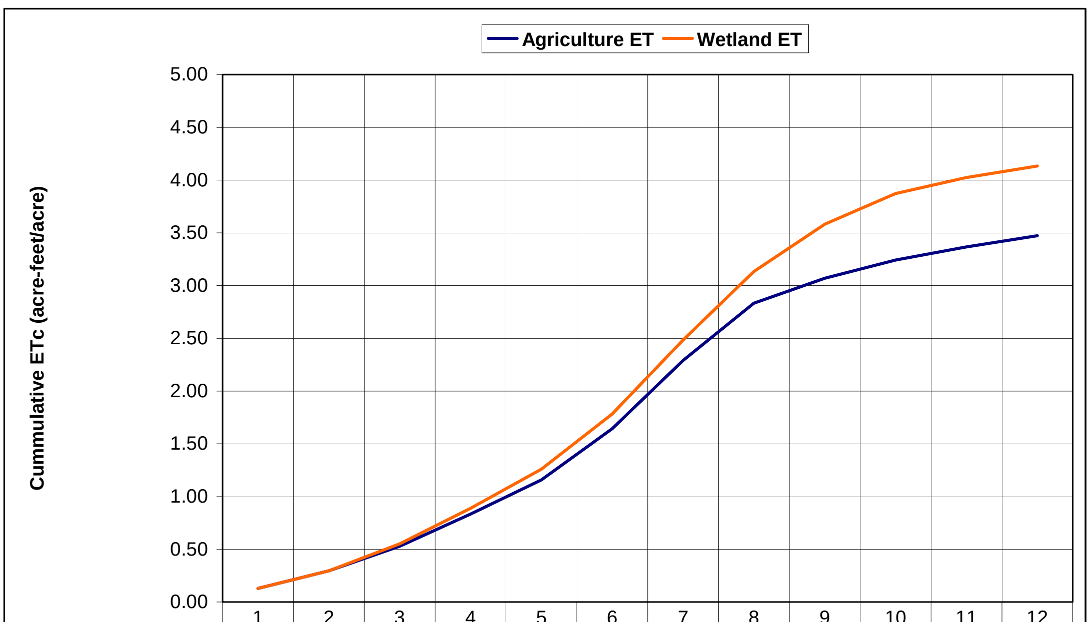
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.12	0.29	0.50	0.76	1.11	1.68	2.26	2.77	2.99	3.17	3.30	3.40
Wetland ET	0.13	0.31	0.57	0.92	1.35	1.97	2.60	3.21	3.66	3.93	4.07	4.18

Figure 8- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Uplands during 2000.



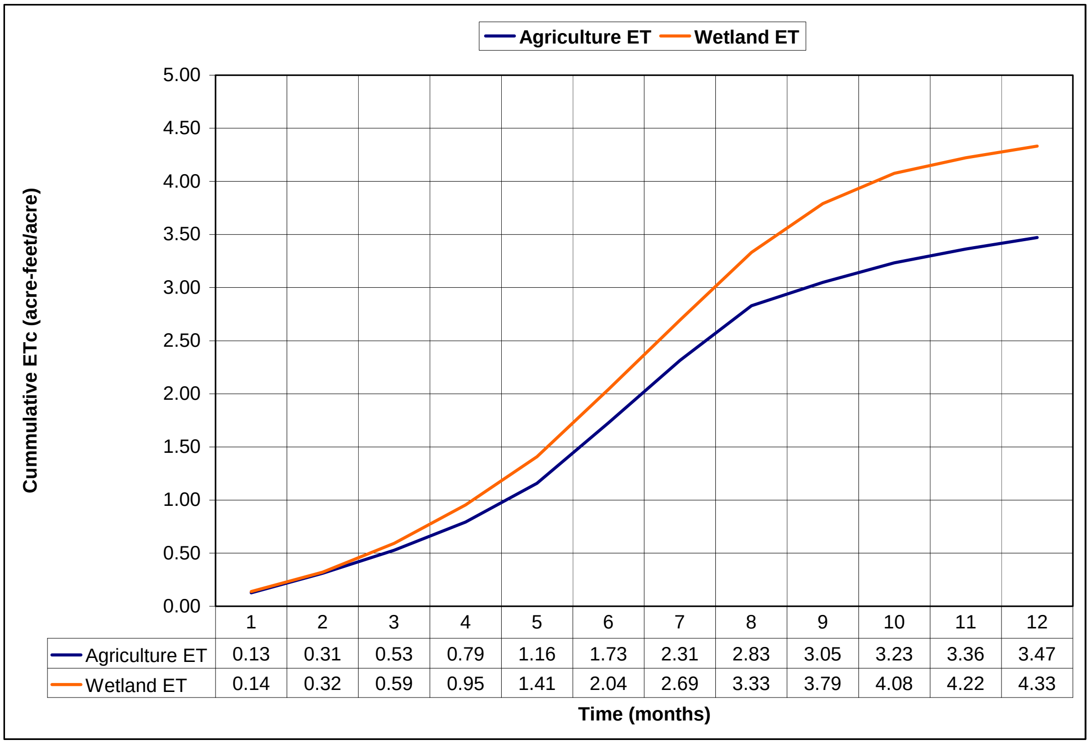
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ETc	0.12	0.28	0.48	0.76	1.12	1.59	2.18	2.71	3.03	3.22	3.35	3.46
Wetland ETc	0.12	0.28	0.55	0.87	1.40	2.02	2.67	3.28	3.72	4.08	4.24	4.35

Figure 9- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the Delta Uplands during 2001.



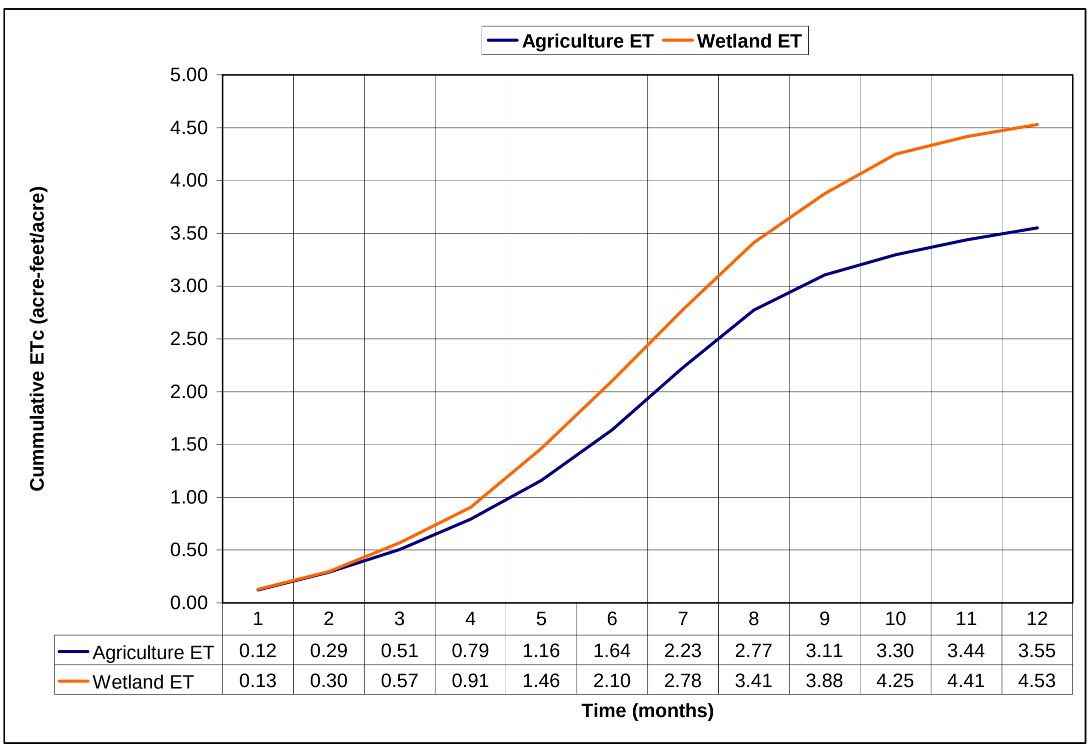
	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.13	0.29	0.53	0.83	1.16	1.64	2.29	2.83	3.07	3.24	3.37	3.47
Wetland ET	0.13	0.29	0.55	0.89	1.26	1.78	2.48	3.13	3.58	3.87	4.02	4.13

Figure 10- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the entire Delta during 1998.



	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.13	0.31	0.53	0.79	1.16	1.73	2.31	2.83	3.05	3.23	3.36	3.47
Wetland ET	0.14	0.32	0.59	0.95	1.41	2.04	2.69	3.33	3.79	4.08	4.22	4.33

Figure 11- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the entire Delta during 2000.



	1	2	3	4	5	6	7	8	9	10	11	12
Agriculture ET	0.12	0.29	0.51	0.79	1.16	1.64	2.23	2.77	3.11	3.30	3.44	3.55
Wetland ET	0.13	0.30	0.57	0.91	1.46	2.10	2.78	3.41	3.88	4.25	4.41	4.53

Figure 12- A plot of cumulative ET_c versus time for agriculture and wetland surfaces in the entire Delta Uplands during 2001.

The monthly total values of evapotranspiration for agricultural crops and wetland vegetation in the Lowlands, Uplands, and Delta are shown in Figures 13 through 15 to illustrate the differences in water use for each crop group between three different water years (1998, 2000, and 2001). The results shown in the figures indicate that land use conversion from agriculture to wetlands will increase evapotranspiration (ET_c) by about 20% in the Delta, assuming that the cattails and tules are grown in standing water. Since it is unlikely that the entire agricultural region of the Delta will be flooded to maintain standing water, changing from agriculture to wetlands will likely have considerably less than a 20% increase in annual water use.

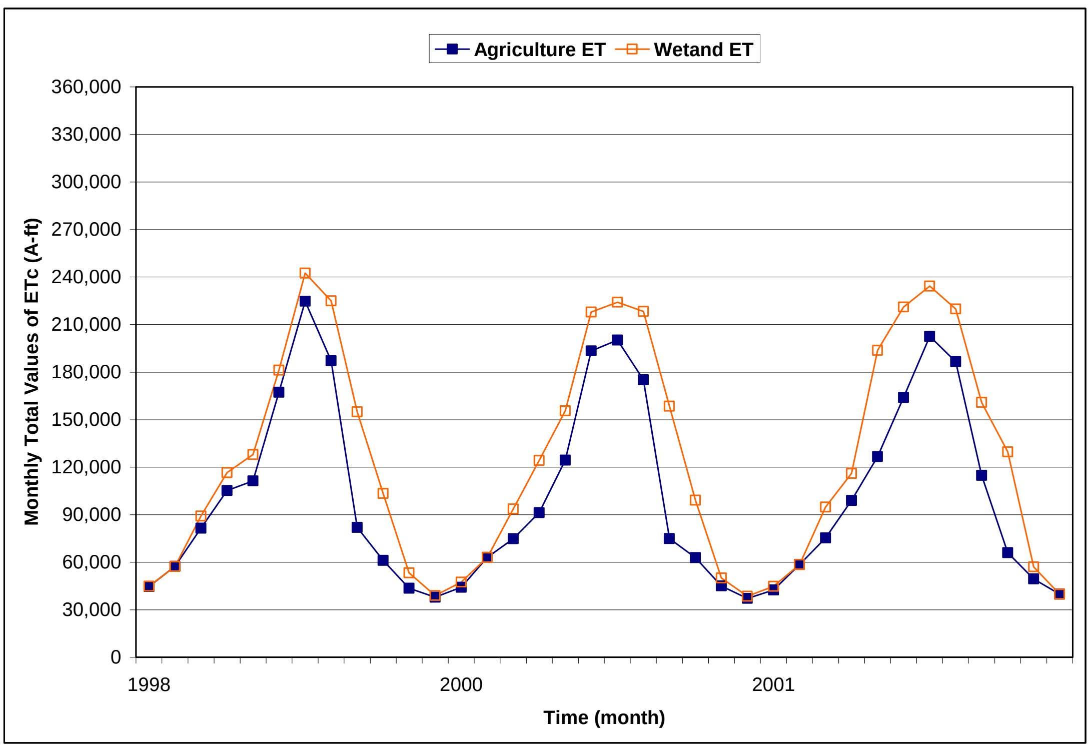


Figure 13- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in Lowlands for the 1998 (wet), 2000 (average), and 2001 (dry) periods including non-irrigated grains and vineyards.

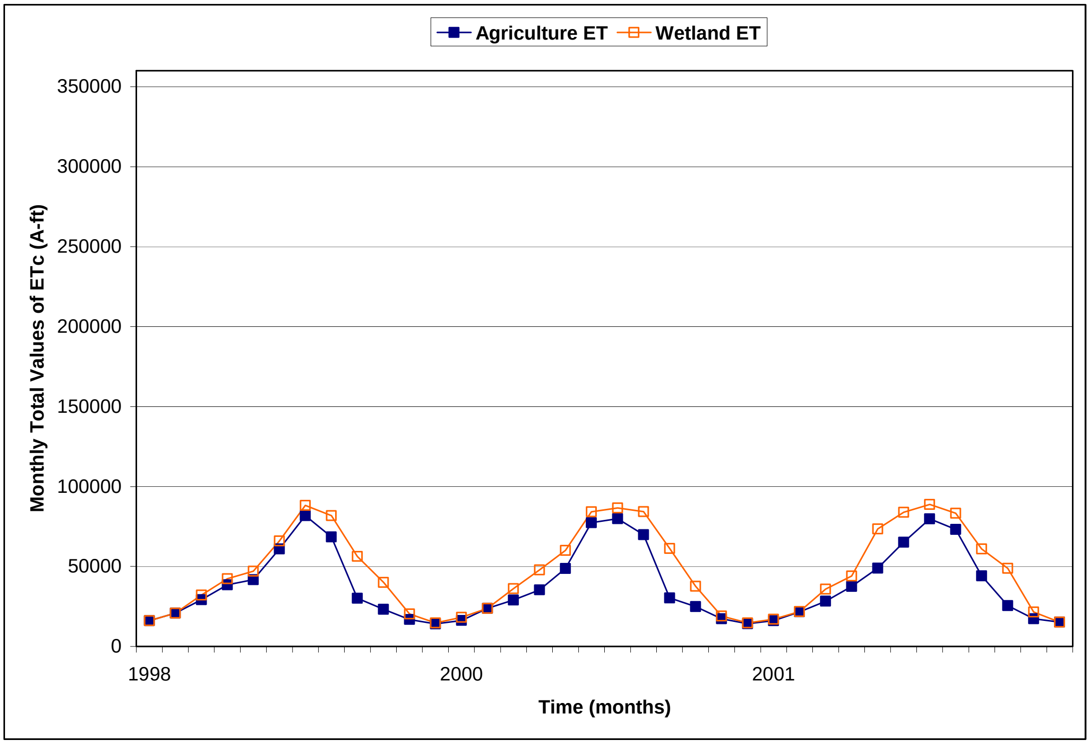


Figure 14- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in Uplands for the 1998 (wet), 2000 (average), and 2001 (dry) periods including non-irrigated grains and vineyards.

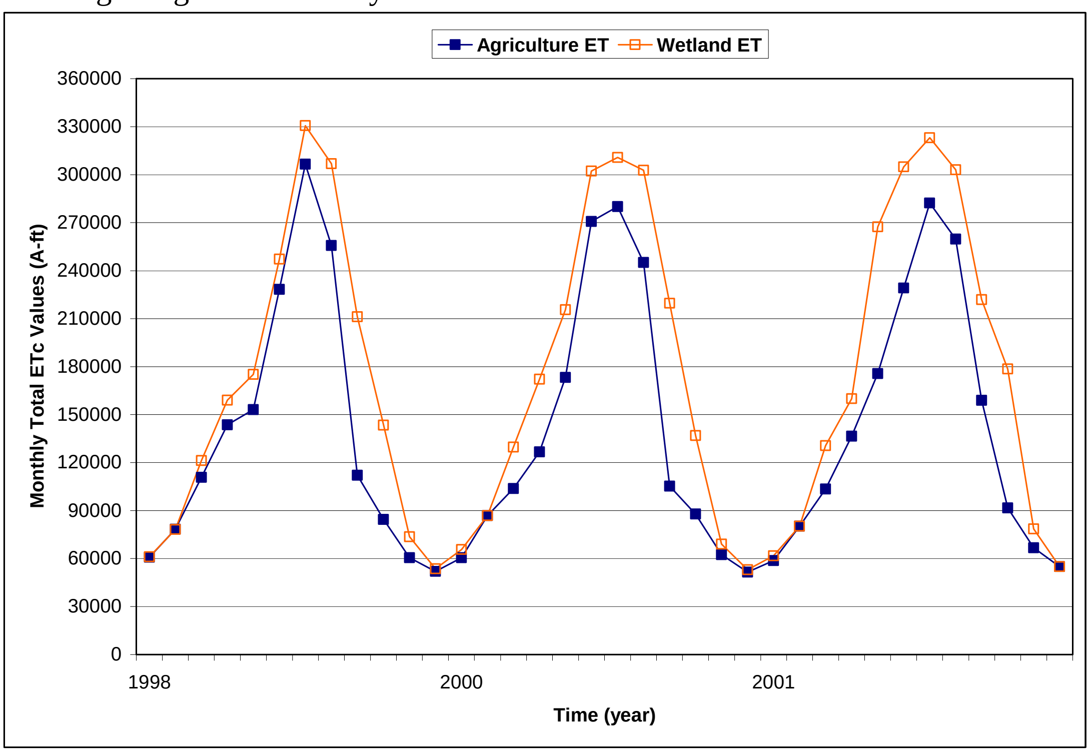


Figure 15- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in the entire Delta for the 1998 (wet), 2000 (average), and 2001 (dry) periods including non-irrigated grains and vineyards.

Figures 16 to 18 show a similar comparison for the monthly total values of evapotranspiration for agricultural crops and wetland vegetation in the Lowlands, Uplands, and Delta to illustrate the other case when non-irrigated winter cereals and grapevines were not converted to wetland vegetation during different water years (1998, 2000, and 2001). The results from the figures indicate that land use conversion from agriculture to wetlands will increase evapotranspiration (ET_c) by about 16% in the Delta.

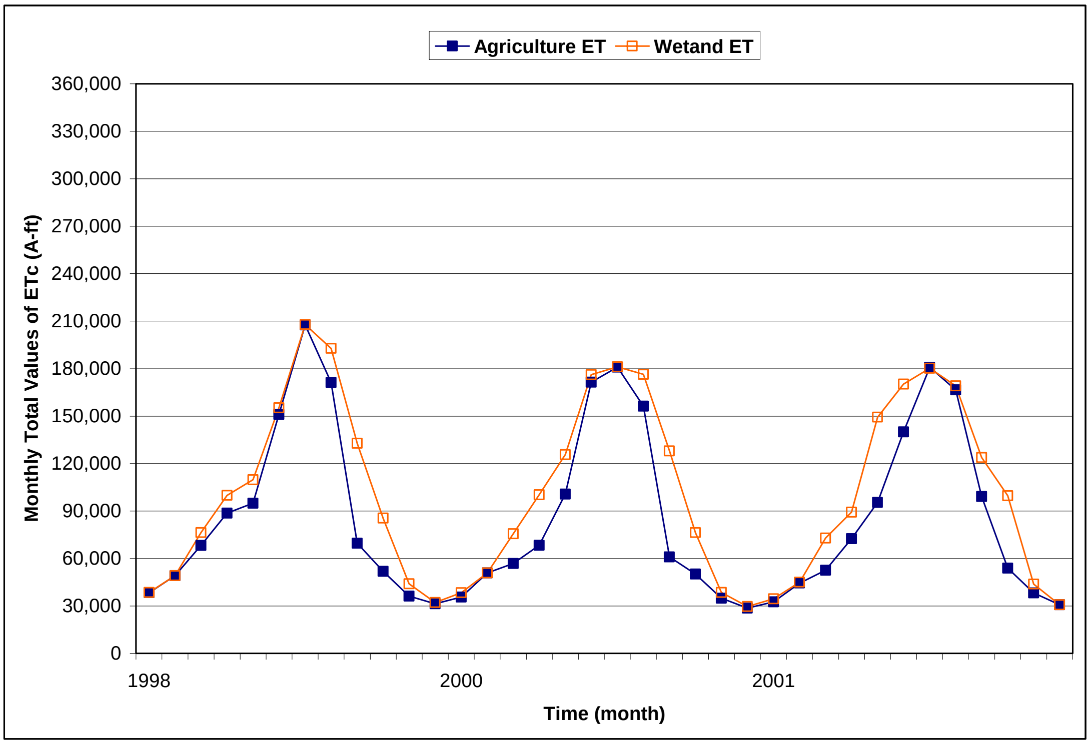


Figure 16- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in Lowlands for the 1998 (wet), 2000 (average), and 2001 (dry) periods not including non-irrigated grains and vineyards.

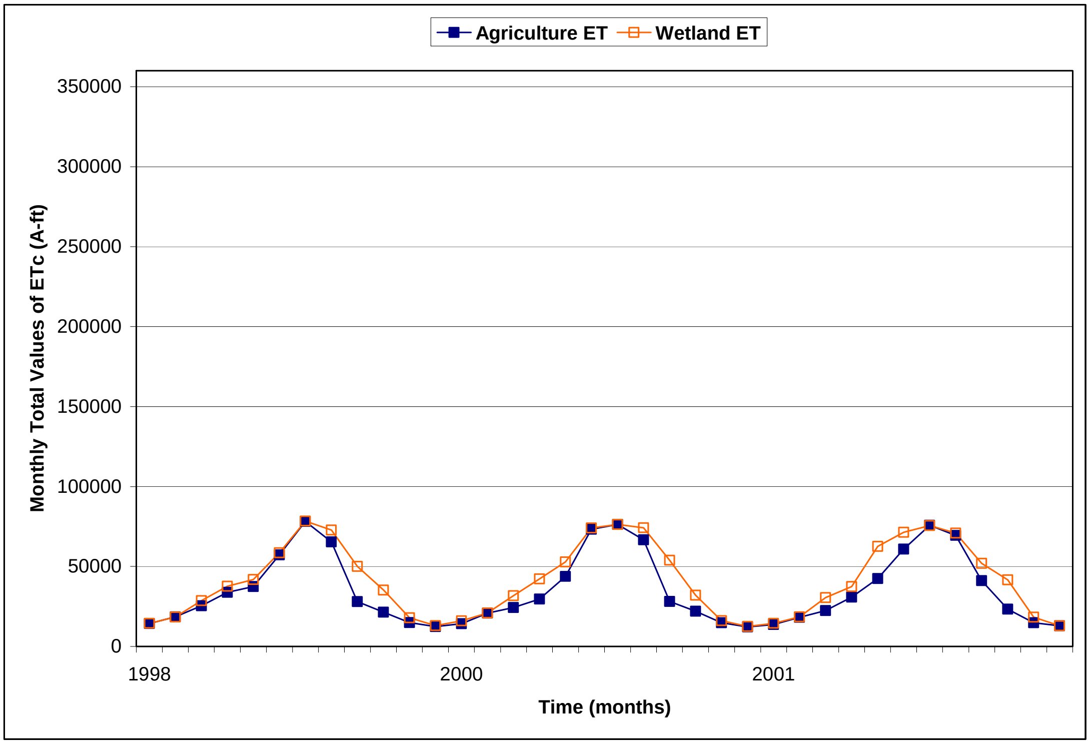


Figure 17- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in Uplands for the 1998 (wet), 2000 (average), and 2001 (dry) periods not including non-irrigated grains and vineyards.

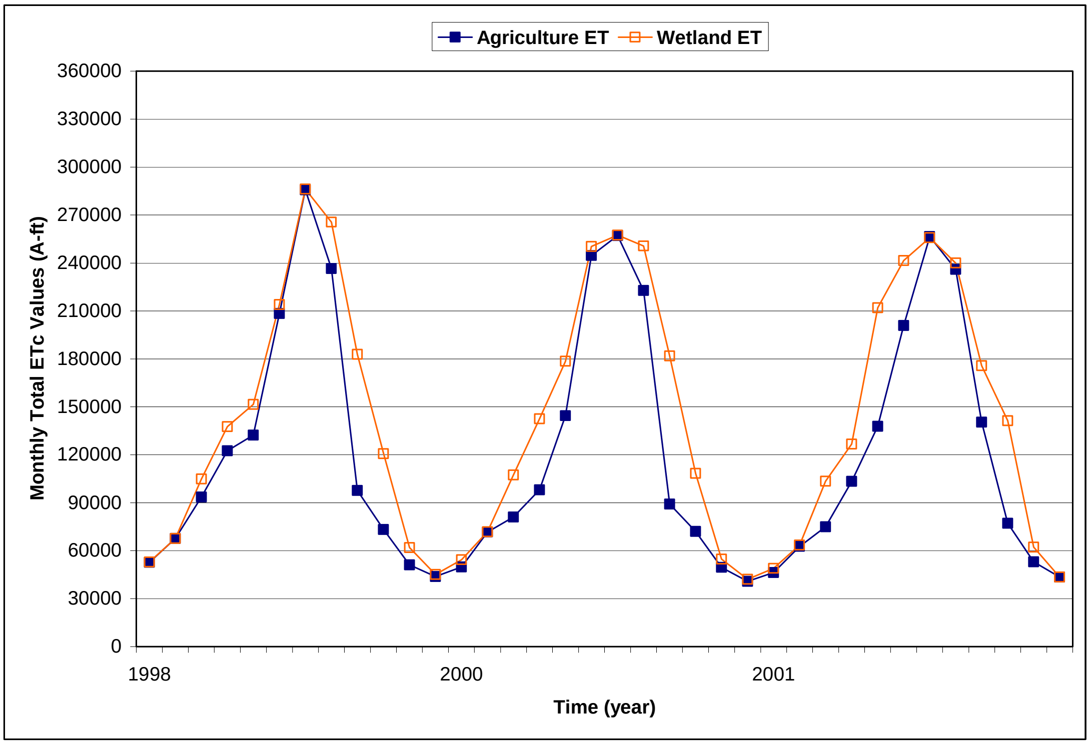


Figure 18- Comparison of monthly total water requirements (ET_c) for agriculture and wetland in the entire Delta for the 1998 (wet), 2000 (average), and 2001 (dry) periods not including non-irrigated grains and vineyards.

Figures 19 through 21 show the average annual ET accrued by agriculture and wetland in the Lowlands, Uplands, and Delta for the water years 1998, 2000, and 2001. The results shown in Figure 21 indicate that agricultural and wetland water use in the Delta range from 1.65 to 1.96 million acre-ft in 1998, 1.65 to 2.06 in 2000, and 1.70 to 2.16 in 2001, respectively.

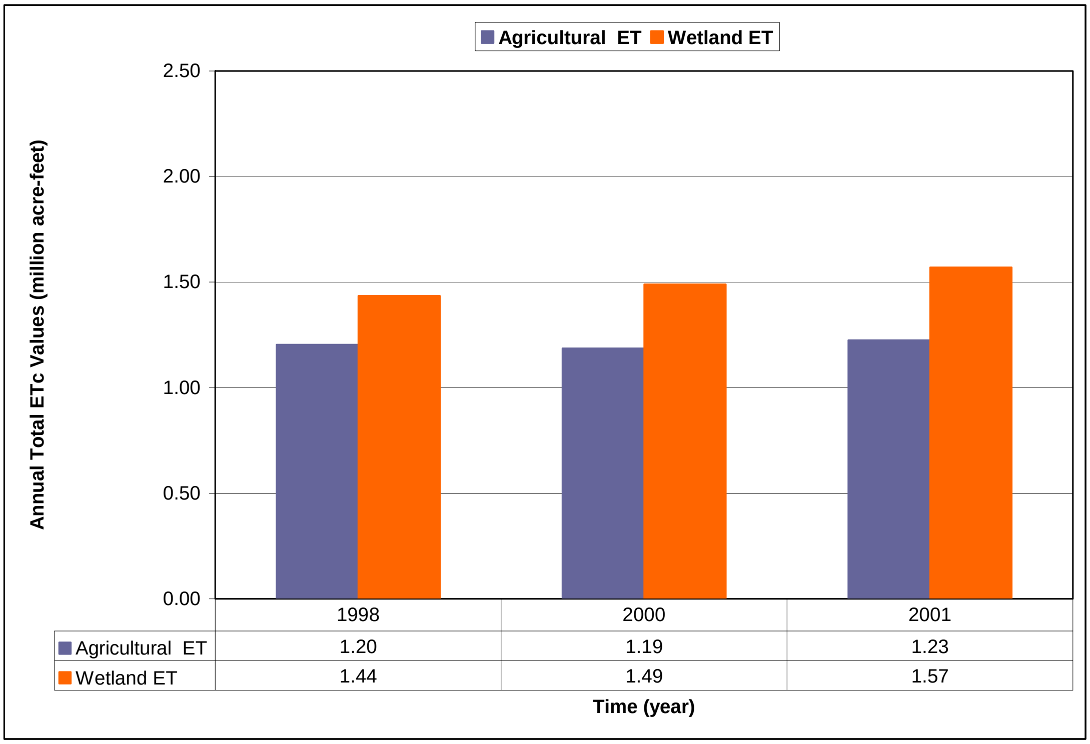
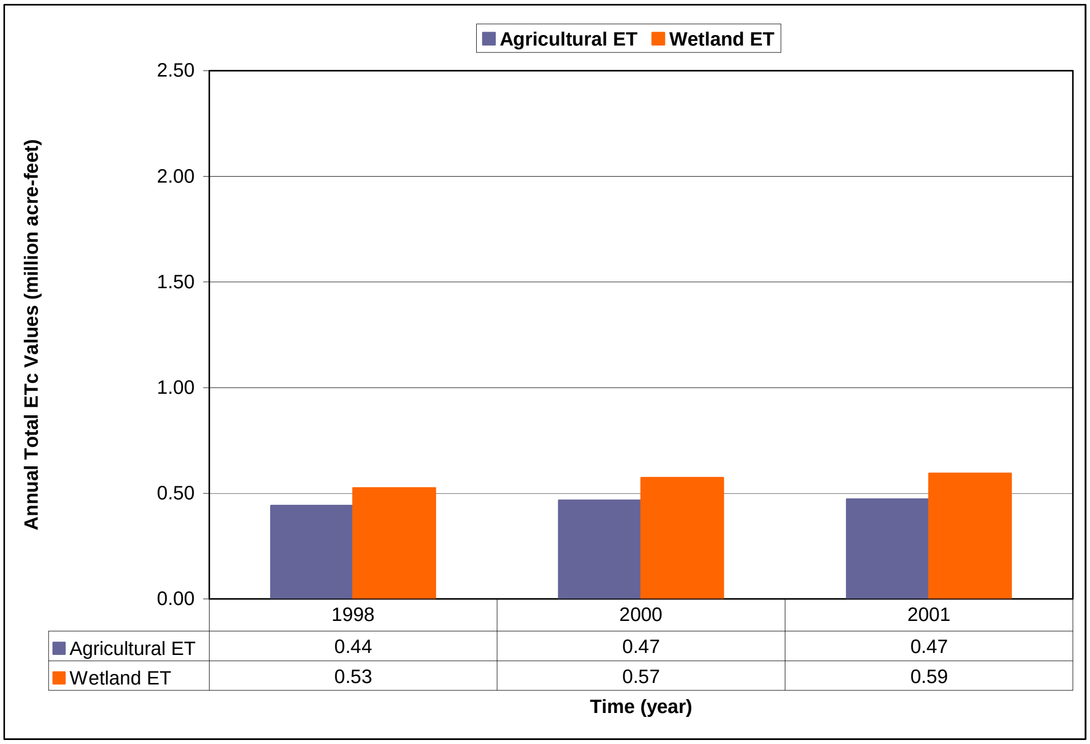
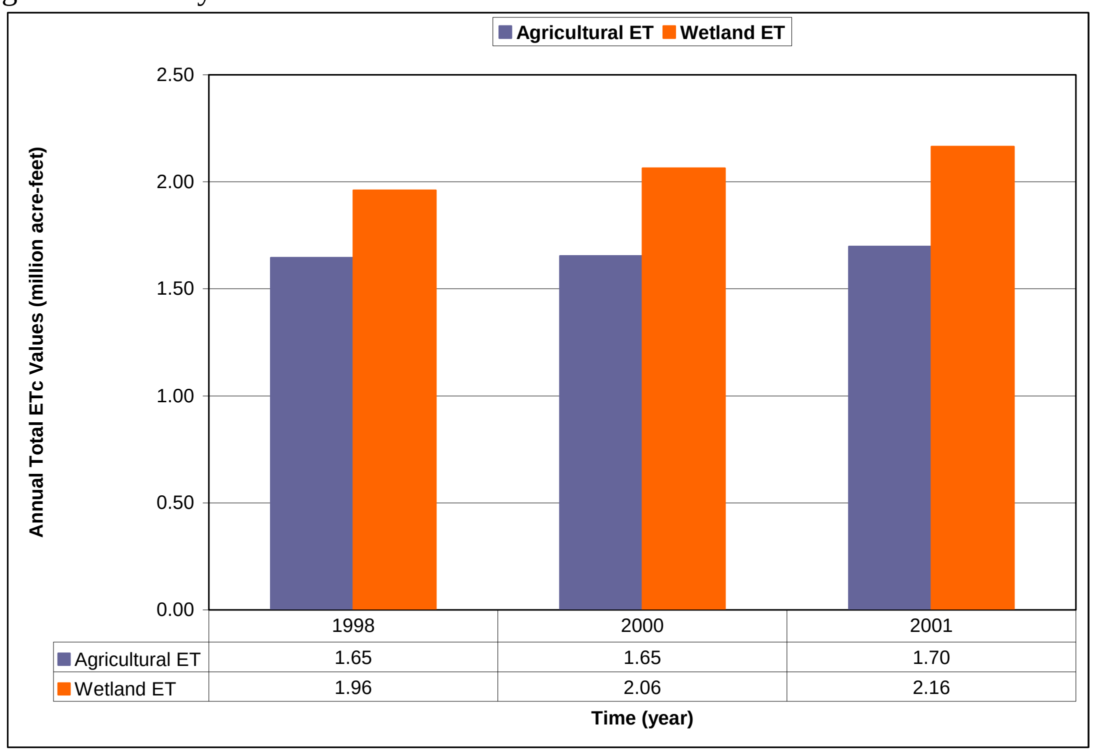


Figure 19- Annual total agricultural and wetland water use (ET_c) in Lowlands for the 1998 (wet), 2000 (average), and 2001 (dry) periods including conversion of non-irrigated grains and vineyards.



	1998	2000	2001
Agricultural ET	0.44	0.47	0.47
Wetland ET	0.53	0.57	0.59

Figure 20- Annual total agricultural and wetland water use (ET_c) in Uplands for the 1998 (wet), 2000 (average), and 2001 (dry) periods including conversion of non-irrigated grains and vineyards.



	1998	2000	2001
Agricultural ET	1.65	1.65	1.70
Wetland ET	1.96	2.06	2.16

Figure 21- Annual total agricultural and wetland water use (ET_c) in the entire Delta for the 1998 (wet), 2000 (average), and 2001 (dry) periods including conversion of non-irrigated grains and vineyards.

Figure 22 illustrates the percentage change per year in water use between agricultural crops and wetland vegetation in Delta for the 1998, 2000, and 2001 water years. The amount of water required to produce agricultural crops in Delta is estimated about 80% of the water use of tules and cattail during a normal water year (2000). Figure 22 also shows that the changes of weather patterns from year to year will also have significant effect on the evapotranspiration rates of the wetland vegetation. The agricultural water use in the Delta is estimated about 84% of the wetland water use in 1988, 80% in 2000, and 78% in 2001, respectively. Recall that the wetland ET_c estimate assumes that the plants are growing in standing water, and the actual ET_c is likely to be less if the surface dries off in a dry year.

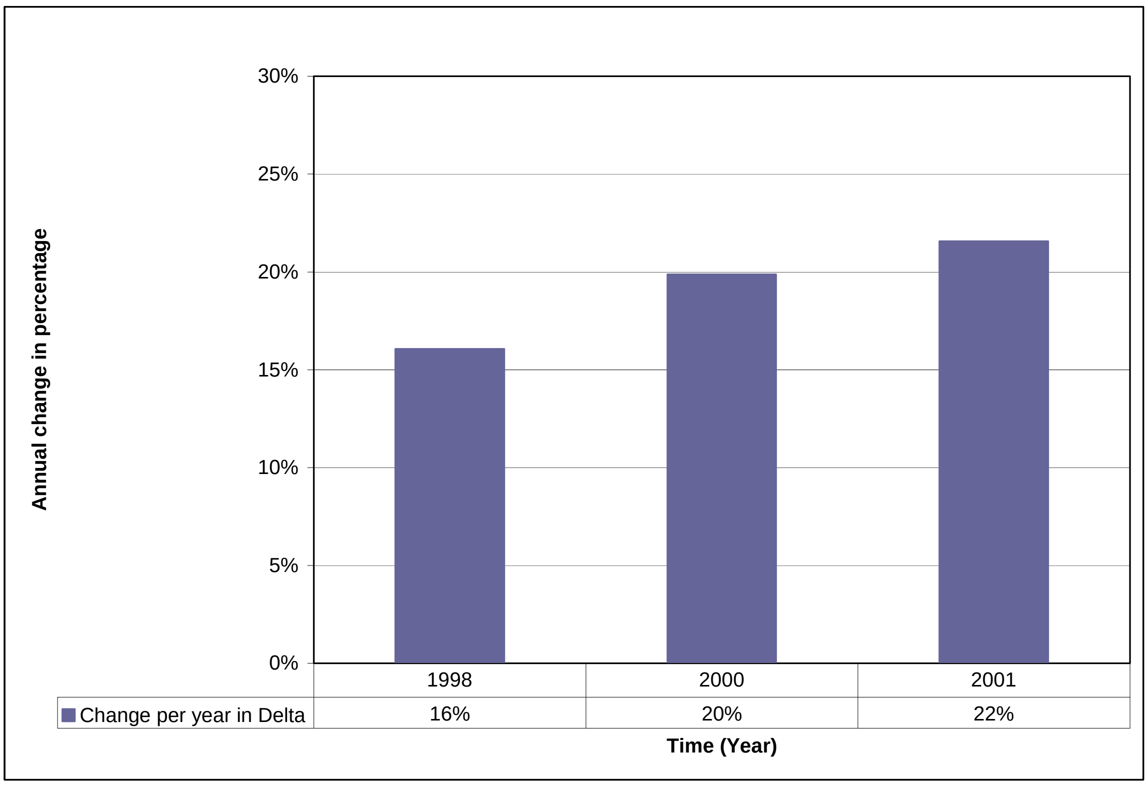


Figure 22- Showing the percentage change per year in water use between agriculture and wetland in Delta in 1998 (wet), 2000 (average), and 2001 (dry) periods including conversion of non-irrigated grains and vineyards.

References:

ASCE-EWRI. 2005. The ASCE Standardized Reference Evapotranspiration Equation. Technical Committee report to the Environmental and Water Resources Institute of the American Society of Civil Engineers from the Task Committee on Standardization of Reference Evapotranspiration. 173 p.

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